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Advantages of virtual reality technology in rehabilitation of people with neuromuscular disorders

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1. Introduction

Computer generated virtual environments (VE) offer capability to provide real time feedback to the user during the practice. The user can see the effect/consequence of his/her action and change the strategy/strength to achieve the desired goal. Such goal can be presented in virtual reality (VR) environment, which is a powerful tool and can efficiently replace tasks from the real life (Rose et al, 2000). Besides augmented feedback, the VR provide an option to practice motor control learning within environment to the people with neuromuscular disorders. Practice, which is essential in motor learning, can be facilitated by designing attractive VR environments, rather fun tasks or games.

The motor control training and muscle strengthening is often performed within clinical environment with predefined tasks and real objects. In contrary recently developed technologies enable development of similar tasks in a virtual world, using computer graphics. The tasks created within the virtual reality (VR) environment offer a capability to provide real time feedback to the subject during practice. Subjects can see the effect of his/her action immediately after the intervention and change the strategy to achieve the directed goal (Holden & Dyar, 2002). Such goal presented in the VR environment may have similar rehabilitation effect as the tasks applied in the real world (Rose et al, 2000). Besides augmented feedback, the VR can also enable selective motor control learning to the people with disabilities (Holden, 2005). The motor learning is defined as a sensory perceptual mechanism by which a new motor skill is learned. An essential component of the motor learning is feedback, which could be in the real world provided by the physiotherapist or in the virtual world provided by visual scenery. In contrary to the task performed in the real environment the virtual environment can be easily changed, adapted to the subject’s needs, speed and level and keep all the modifications of eventually complex virtual scenarios within controllable and reproducible limits. Successful applications have been shown in stroke subjects (Sisto et al., 2002, Yang et al., 2008).

In the proposed chapter two various approaches are presented; a selective motor control training using position controlled single-joint rehabilitation robot (Cikajlo, 2008) and virtual reality balance training (VRBT) via telerehabilitation service (Smart Home iRiS). Both approaches apply VR technology to implement rehabilitation tasks into the clinically proven rehabilitation devices. In the selective motor control training 10 neurologically intact individuals and a cerebral palsy (CP) child participated to demonstrate the novel concept. The results showed a significant progress in single joint torque control. The motor control training may also have significant impact on CP child's gait pattern, one of the major rehabilitation issues in CP children treatment. The dynamic balance training within virtual environment offers various tasks that require from the subject, standing in the dynamic balance frame, anterior-posterior and medio-lateral movements. In the case study a stroke subject demonstrated comparable clinical outcomes to conventional therapy. Additionally the telerehabilitation approach enables the subject to practice balance at home while the physiotherapist can supervise and provide instructions remotely.

2. Rehabilitation issues

Rehabilitation of neurologically impaired subjects tends to enhance motor control skill, which is claimed to be a direct result of repeatable practice (Sisto et al, 2002). The repeatable practice, particularly the frequency and duration of the practice, are often limited in rehabilitation. Physical therapy treatment in the rehabilitation center is often limited to three times per week in the acute settings and also the individual treatments can not last more than an hour due to fatigue. But to maximize the recovery an intensive treatment should be considered as the intensive rehabilitation may lead to better functional outcomes. Besides intensity, also repeated and targeted actions in therapy play an important role in the outcome enhancement. The goal is to achieve independence in a short time, but that is the limitation in the existing health care systems. One of the possible solutions in the future might be a telemedicine – a home based rehabilitation (Deutsch et al, 2007).

The improvement of functional outcomes could be achieved only with a certain level of subject’s motivation and further enhanced with the variety of repeatable in targeted actions in the environment where the events can be added in the controllable manner. But it is nearly impossible to add unexpected events in the real life experiment in a safe and repeatable manner. Therefore the application of virtual environment may contribute to the solution of the problem.

3. Virtual reality technology in rehabilitation

Virtual environment (VE) is immersion of a person or an object in a computer generated environment such that the person experiences stereovision, correct perspective for all objects regardless of the motion, and objects in the environment move according to the subject motion (Kenyon et al, 2004). In order to assure these characteristics, applications of certain technologies are required (Burdea & Coiffet, 2003). These technologies apply several sensor types to generate artificial sensory information to allow individuals to experience and interact with the environment. But, the interaction and experience must be realistic enough, therefore the computer must generate new images fast enough to assure movement adequate to real-time responses. Simulation of the 3D environment can be presented through the immersion or nonimmersion scenario (Sisto et al, 2002). The immersion scenario is referred to the use of a head-up mounted display (HMD), equipped with 3D tilt sensor that tracks all the changes and sends them to the virtual environment. Hereby the important issue is the synchronization between the head movement and presented image. In the case when the image update is to slow and not synchronized with the head movement, the subject may experience dizziness, nausea or other inconveniences, which may cause sickness. The state of the art, multiperson, room size, high resolution 3D video and audio system is the CAVE™ (University of Illinois, Chicago). The nonimmersion VE can be displayed on computer monitor or projected to the large screen in front of the subject. These displays have been preferred to use in clinical studies due to the relatively low price and no reports on cyber sickness (Holden, 2005).

The concept of rehabilitation is based on repetition of movement, providing feedback and motivation. Repetition is important for local and central nervous system, resulting in motor learning and cortical changes. Besides repetition of the movements during rehabilitation the tasks must be linked to some successfully accomplished assignments, i.e. target oriented approach. The subject practices movements during the rehabilitation treatment with medical professionals' assistance, but only can keep up with the extensive practice, when being well motivated. Therefore the motivation factor plays an important role in rehabilitation practice (Holden et al, 2002). And here the virtual reality (VR) comes in handy, providing visual feedback, repetitive practice and motivation. The VR technology offers enormous variations of objects, orientations, creative environments, augmented feedback. Besides that all the parameters of the VE like objects size, position, velocity, movement's speed, augmented support, etc can be varied under supervised repeatable conditions.

It has been reported on successful use of VE training in hemiplegia, where the upper extremity reaching task applied 16 times for 1 to 2 hours resulted in clinical and functional motor improvement (Jack et al, 2001). The authors also pointed out that VR offered motivation and fun for practice. Some authors investigated the effect of VE on visual function in rehabilitation which may be also important in the recovery of motor function, because the visual system is needed to guide movements (Sisto et all, 2002).

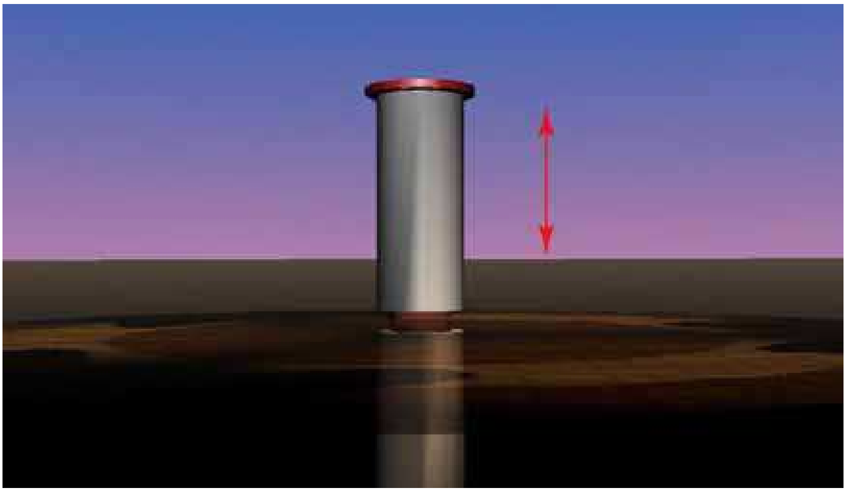

Fig. 1. The virtual reality environment for maximal torque assessment. The subject was asked to push the top button as high as possible by generating a knee joint torque.

Some examples of VE for motivation in maximal dynamometer based joint torque assessment (Fig. 1), selective motor control training (Fig. 2) and VRBT (Fig. 3) are presented.

Their common attributes of the presented VE in the nonimmersion scenario running on the commercially available inexpensive personal computer with 3D graphic adapter. In cerebral palsy children the VE with a growing cylinder with top red button (Fig. 1), associated with the amount of the generated joint torque presented a considerable issue and motivated the child to play the game. The goal was to push the top red button higher and higher by generating joint torque in isometric and isokinetic mode (Dvir, 2004) and simultaneously assess muscle electromyography to identify muscle power and selective motor control. The selective motor control training VE (Fig. 2) applied trajectory controlled dynamometer to impose joint movement, while the task required from the subject to generate adequate joint torque to move the object (bee) flying in the virtual office and hitting targets (flowers) in the VE. When the object touched the target, the target disappeared and at the end of the game the number of hits scored. Besides the difficulty level was pre-defined by the level of generated joint torque tolerance.
The VE for VRBT was designed as a game of virtual walk. The task required from the subject to "walk" by tilting the dynamic standing frame (Cikajlo & Matjačić, 2009; Medica Medizintechnik, Germany) forward and "turn" by tilting the frame in frontal plane. The task (Fig. 3) was divided in three difficulty levels, each comprising additional obstacles on the way.

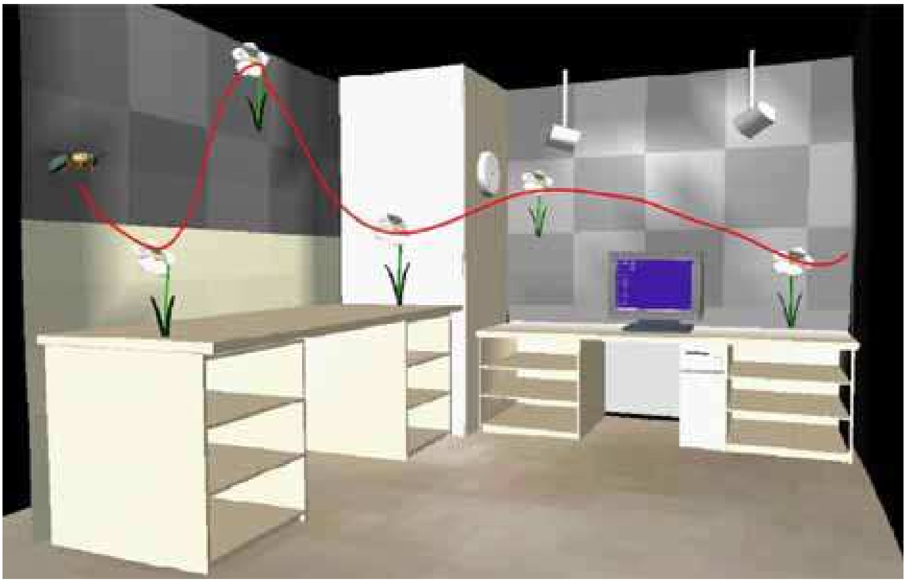

Fig. 2. The virtual reality environment for motor control learning; by generating adequate joint torque the subject can move the object (bee). The extension knee torque causes upward movement and the flexion torque a downward movement of the object, while the object moves in transversal plane synchronized (time) with the dynamometer.

In the first and the easiest level (level 1) there were no obstacles on the tree lined path, where the subject passed by the woman on the left and at the dolphin statue turned left and continue to the buffet, where the obstacles were two tables and chairs. Afterwards the subject made a turn around the tables and returned back to the dolphin statue and continued his way passing by the security guard to the entrance of the building. When the subject entered through the door, the task restarted from the begging. At the second level (level 2) four benches were added as obstacles which the subject needed to avoid. And the third level (level 3) added three additional cans and two pools near the dolphin statue (Fig 7, Fig. 12).

VE in rehabilitation is believed to positively influence on practice, because of the ability to make tasks easier, less dangerous, more customized, fun and easy to learn due to the feedback provided. Some studies have examined these advantages and provide experimental evident that motor learning in the VE may be superior (Holden, 2005).

Fig. 3. Virtual reality technology was used to implement the dynamic balance training task, where the subject “walked” through the scenery by tilting the apparatus. The task runs in web-explorer, which made it easy to implement it in the telerehabilitation service.

4. Telerehabilitation

The low cost personal computer based VE equipment is nowadays inexpensive and available to wide range of users and will eventually allow VE based rehabilitation in locations other than the rehabilitation center hospital, e.g. a patient’s home. Patients who experienced any disabling event such as stroke will most likely return to their home after the rehabilitation treatment in the rehabilitation hospital. Nowadays the treatment is becoming more and more expensive and also effective, therefore we may expect that the patient would return to his/her home sooner than in the past. But the majority will still need to continue with the rehabilitation through the outpatient service or through the home care. For those patient who do not own a vehicle or lack of public transportation or live in the remote areas the outpatient service can present a barrier. On the other hand the insurance companies would most likely prefer a service that could be performed on patient's home, the patient would be given instructions over the communication media and if possible posses a device that could evaluate his functional motor capabilities. All this would significantly reduce the number of outpatient visits and in some cases reduce the length of the hospital treatment.

The remote rehabilitation or telerehabilitation service can be provided through the broadband internet connection between the medical centre and the user's home environment or local medical institution. The presented approach has been demonstrated in the modern smart home iRis (www.ir-rs.si/en/smarthome) equipped with rehabilitation aids integrated into the smart home's technologies. The application runs on the personal computer connected to the living room 42" LCD, which could be remotely operated, even from the electric wheelchair. The non-immersion scenario VE (Fig. 3) was designed to run in web-explorer on the LCD and enabled the subject to practice balance in the home environment. The supervising physiotherapist or other medical professional in the medical centre could monitor remotely the VE and the task being performed in real-time. The currently available technology can enable the VE monitoring over the internet using the web browser (Internet Explorer, MicroSoft with blaxxun plug-in). Moreover, the videoconference session with the rehabilitation centre was on his disposal anytime in order to provide additional tasks and important advices to the subject during the dynamic balance training. The videoconference was established by using a free-ware Skype (Skype Technologies S.A., Luxembourg, EU). Full-duplex voice and video enabled the physiotherapist to advise the subject to correct the posture during the therapy. Data of each training session were recorded and presented important information on subject's activity or inactivity and an objective information on subject's balance capabilities. On the basis of that information the subject is invited to the outpatient visit to the rehabilitation centre, where other clinical tests can be carried out.

5. Methods

In the chapter two various approaches of VR applications are presented:

- VR based motor control training using dynamometer
- VR based dynamic balance training with telerehabilitation service

Both used nonimmersion VR scenarios presented on the LCD. The first approach with the dynamometer demonstrated the power of visual motivation and the possible application of selective motor control training based on gait kinematic parameters. The second approach demonstrated the use of VR to motivate the stroke subject for balance training. Besides the task was supervised remotely through the internet and the subject was given instructions via the videoconference session.

5.1 VR based motor control training using dynamometer

5.1.1 Equipment

The proposed system (Fig. 4) consists of Biodex System 3 dynamometer (Biodex Medical Systems, New York, USA) with additional analog output and optional serial interface, personal computer with multifunction DAQ board (NI-PCI- 6259, National Instruments, Austin, Texas, USA) servicing data assessment, Biodex control, graphical user interface (programmed in Matlab, The MathWorks, Inc., Natick, MA, USA) and VR environment (blaxxun Contact VRML plug-in). Muscle activity was measured by electromyography (EMG), MyoSystem 2000 (Noraxon U.S.A. Inc., Arizona, USA).

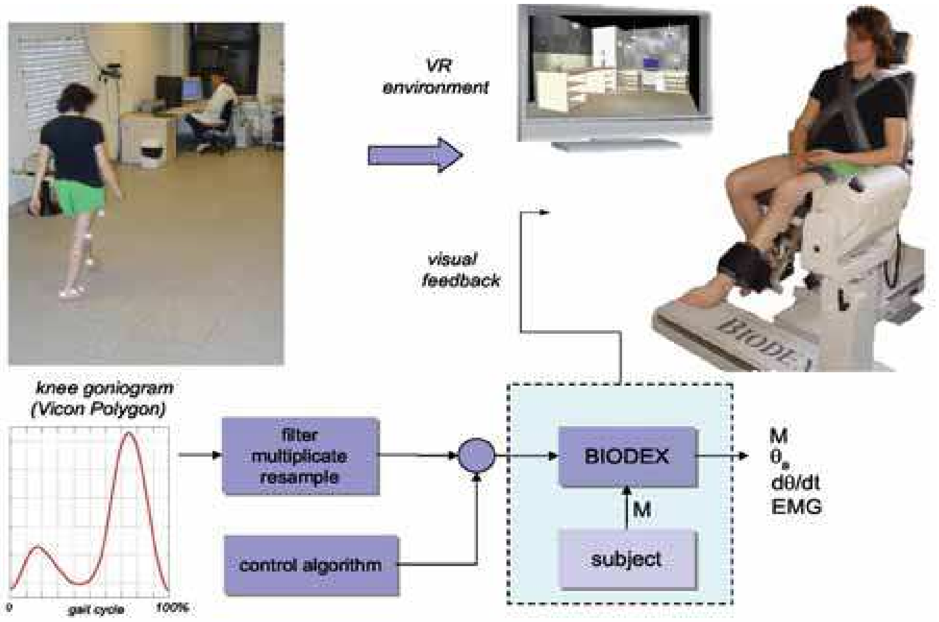

Fig. 4. The goniogram controlled dynamometer performs pre-programmed joint movement while the subject moves the object in Virtual scenery by generating joint moment. The goniogram from gait analysis software is applied in position control of the dynamometer. The subject's task is to hit all the targets (flowers) by providing joint moment (adequate to avatar's vertical position) while the avatar (bee) is synchronized with the goniogram.

5.1.2 Dynamometer control

The control of a dynamometer, which is in general intended for isokinetic or isometric dynamometry (Dvir, 2004), has been modified to the level that enabled position control. The joint goniograms (joint angle per gait cycle), assessed during participating subject's gait analysis, have been averaged and normalized to a single gait cycle (GC). The obtained GC goniogram was resampled and presented the desired trajectory in position control of the dynamometer (in this case can be considered as a 1-dof robot). Thus the angular velocity of the dynamometer in controlled mode was determined by the selected goniogram and sample time/GC time. Simultaneously the subject was asked to generate the adequate joint torque in order to accomplish the required task. The joint torque was measured by Dynamometer’s built-in torque sensor and calibrated on-line to compensate for gravity (Herzog, 1988). The information on joint torque was introduced into the VR environment, where the moment value caused an adequate movement of the object (Fig. 4).

Virtual reality environments have been designed to provide feedback information to the user/subject. In the first stage of development two specific VR tasks were designed:

- Environment for maximal joint torque (Fig. 1) assessment with specific visual object that stimulated the subject to put his maximal effort to accomplish the task. The subject was asked to push the top button as high as possible by generating a knee joint torque;
- Environment for motor control learning (Fig. 2) where the specific task required from the subject to generate specific joint torque and control the object in the VR environment to accomplish the task - by generating adequate joint torque the subject can move the object (bee). The extension knee torque causes upward movement and the flexion torque a downward movement of the object, while the object moves in transversal plane synchronized (time) with the dynamometer.

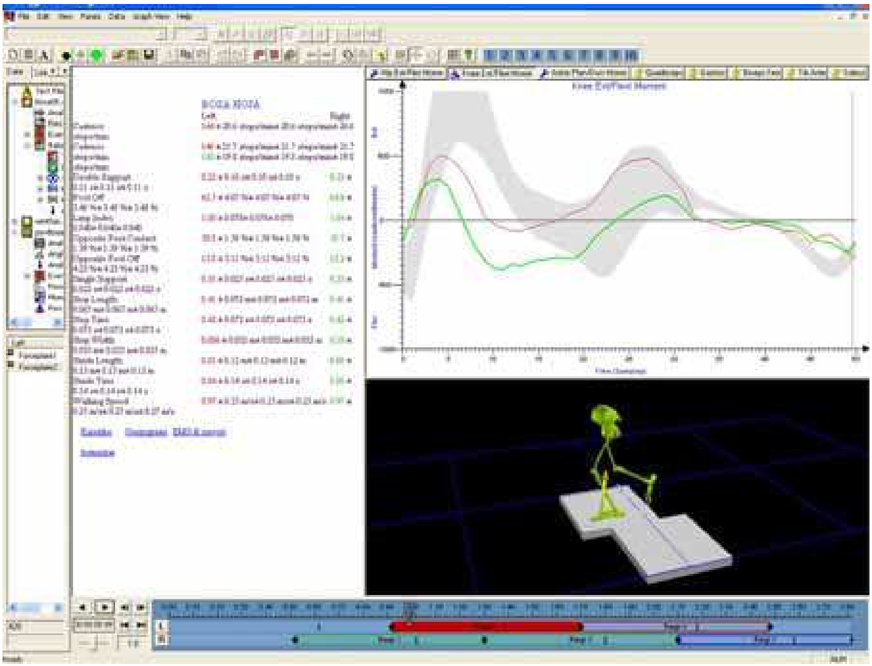

Fig. 5. Knee torque per gait cycle assessed and analyzed with commercial gait analysis software was exported to file and uploaded into developed program for dynamometer control.

The VR task required from the user to push the cylinder and the button as high as possible (Fig. 1) or hit as many targets as possible (Fig. 2). The VR object (bee) moved in the environment in transversal plane over time, synchronized with the joint goniogram, while the object's vertical movement was related to the generated joint torque value. The joint extension torque provoked the object's upwards movement and the flexion torque moved the VR object downward. The targets were positioned in the VR world in a way that the generated joint torque trajectory (Fig. 5) would equal to the moment reference value [8] during the gait, if the subject succeeds to hit all the targets. The target was considered hit when the generated torque was within the selected limits. The selected limits defined influenced on the task execution difficulty and thus defined the difficulty levels. For the level 1 the torque variation could be within 30% (±15%), for the level 2 20% (±10%) and for the level 3 10% (±5%) of the accurate torque, required to hit the target.

5.1.3 Subjects

10 neurologically intact volunteers (27.2 SD 3.5 years, 71.8 SD 8.1 kg, 173.4 SD 5.5 cm) participated in the virtual environment task and protocol development and preliminary evaluation. The volunteers had no muscular-skeletal impairment or any disease that would affect motor control capabilities. Besides, a 12-year old boy with cerebral palsy (CP II, spastic diparesis, 149 cm height, weight 48kg, functional electrical stimulation 1-ch peroneal nerve 1 hour/day, crouch gait, poor selective motor control), a patient of the Rehabilitation hospital, voluntarily participated in the case study due to his good cognitive capabilities. The child had no prior experience with VR.

The methodology was approved by local ethics committee and the subjects/the subject's parents/ gave informed consent.

5.1.4 Protocol

The subjects were seated on the Biodex reclining chair. Stabilization of the subjects was achieved by placing velcro straps across the chest, around the waist, just above the right knee and just above the right ankle, which secured the right lower leg to the input shaft of the dynamometer. The dynamometer lever was set to 45^o flexion and the dynamometer operated in goniogram position control (Cikajlo, 2008) or isometric mode (Dvir, 2004). In addition, we visually aligned the estimated transverse rotational axis of the dynamometer. The surface EMG electrodes were placed on the right lower extremity's quadriceps muscle. The entire test procedure was repeated for the subjects over 3 consecutive days at approximately the same time of the day to limit the extent of possible diurnal variation. Each day the VR task for maximal joint torque assessment (Fig. 1) was performed; 3 times for knee flexion and 3 times for knee extension. The protocol proceeded with the VR task for selective motor control training (Fig. 2). During the task execution the surface EMG of quadriceps muscles were assessed. On the first day a slow (GC = 15s) task speed was selected for each difficulty level, on the second day the task execution speed was increased for 50% (GC = 10s) and on the third consecutive day for additional 100% (GC =5s), in total 3 times faster than the task execution speed at the beginning.

5.2 VR based dynamic balance training with telerehabilitation service

5.2.1 Balance training

Balance training was based on dynamic balance training standing frame made of steel base construction placed on four wheels, which when unlocked enable the apparatus mobility. The later is important in clinical environment where the rehabilitation aids have no dedicated space. The standing frame is made of aluminum and fixed to the base with passive controllable spring defining the stiffness of the two degrees of freedom (2 DOF) standing frame. The stiffness of the frame is set up according to the individual's requirements. On the top of the standing frame a wooden table with safety lock for holding the subject at the level of pelvis was mounted.

The subject was standing in vertical position in the balance trainer with his hands placed on the wooden table in front of him and secured with safety lock from behind at the level of pelvis, preventing to fall backward (Fig. 6). The standing frame can tilt in sagital and frontal plane for ±15°. The tilt of the balance standing frame (BalanceTrainer, Medica Medizintechnik, Germany) was measured by commercially available three-axis tilt sensor (Xsens Technologies, Enschede, The Netherlands).

The task for dynamic balance training was based on subject's movement, i.e. weight transfer in sagital and frontal plane, resulting in BalanceTrainer tilt. The tilt, assessed by sensor mounted on BalanceTrainer frame, resulted in the immediate action in the designed virtual environment (Fig. 3).

Fig. 6. Telerehabilitation in practice. A physiotherapist (right photo) is supervising and assisting the subject remotely during dynamic balance training (left photo) in Smarthome (Smart Home iRiS) The BalanceTrainer apparatus was equipped with tilt sensor and detected the subject's movement. Adequately the virtual environment changed and the subject was required to avoid obstacles and to reach the goal – the door in the building.

5.2.2 Subject

In the pilot study a 47 year old subject (male, 180 cm, 80kg, intracerebral hemorrhage a month before the therapy) with right side affected and a slight motor dysphasia and dysarthria. The subject has been cardiovascular compensated (Julu et al, 2003), without additional diseases and medications that may affect the balance. His cognitive functions were preserved, allowing him to follow the given instructions.

The methodology was approved by local ethics committee and the subjects gave informed consent.

5.2.3 VR supported telerehabilitation protocol

The testing of the VE based telerehabilitation balance training took place in the SmartHome Iris (Smart Home iRiS), a well equipped demonstrating apartment for people with special needs. The subject was standing in the BalanceTrainer (Fig. 6 left), secured with safety rod at the pelvis level, and placed his hands at the front table. In front of the subject was a LCD screen with a multimedia camera with built-in microphone on the top. An engineer who was responsible for the subject in the SmartHome Iris established a videoconference call with the physiotherapist who was located in the remote room. The physiotherapist could see the subject and provided him instructions how to correct his posture while the subject was performing the VE based task (Fig. 7).

The subject performed the therapy five times a week, each time for 17 to 20 minutes. On the first week the subject used level 1 of the VR task for balance training, on the second week, when the physiotherapist estimated the subject's progress, the training started with level 2 and on the third and fourth week with level 3.

The subject balance capabilities were also assessed with clinical instrument (Berg Balance Scale – BBS, Berg et al., 1992) at the beginning of the therapy and after four weeks. Besides BBS, the standing alternatively on the healthy and the affected lower extremity, the »timed up and go« test and the 10-m rapid walk test were also performed.

Between the VE task sessions the subject took part in other standard neurotherapeutic programs (cognitive rehabilitation, treadmill training, gait…, etc), but no balance training.

Fig. 7. Telerehabilitation task in VE (perspective view). The subject moved in the VE by tilting the standing frame. The designed task's path (red line) required from the subject to transfer the weight from left to right side and vice-versa and in this manner perform voluntary balance control training.

6. Results

6.1 VR motor control training using dynamometer

The knee joint torque assessed in neurologically intact volunteers when performing the maximal moment VR task extended between 111.3 (SD 23.2) Nm and 122 (SD 29.5) Nm (Table 1).

The obtained joint torques were normalized and averaged on GC and contrasted to the knee (Fig. 8) normative (Winter, 2005) torque (reference values), which was generated in neurologically intact subjects during gait (shaded area). In the upper Fig. 8 the triangles presents the targets (flowers) from the VR environment. There were no significant changes in joint torques when the task difficulty level was changed, but the generated torque was noticeably delayed with increased velocity (target 2 in Fig. 8). There were almost no changes in EMG responses in neurologically intact subjects (Fig. 9). The expected knee extensor muscles were activated simultaneously with the generated joint torque. The Fig. 9 below shows the actual knee joint angle during VR task execution normalized on GC.

MaxTorque	Variable	Day		
		1	2	3
Knee / Nm (SD)	extension	122.6 (29.5)	112.9 (22.2)	111.3 (23.2)
Knee goniogram - control	Difficulty level	Velocity		
		1	2	3
hits / %	level 1*	94.0 (12.9)	94.9 (10.1)	95.4 (12.8)
	level 2*	93.7 (14.1)	91.4 (14.9)	88.5 (15.9)
	level 3*	64.0 (32.1)	61.1 (27.4)	54.3 (28.0)

*paired T-test (statistically significant - $p < 0.05$)

Table 1. Numerical values of generated maximal joint torque for each day and percentage of hits for each difficulty level and velocity in neurologically intact volunteers.

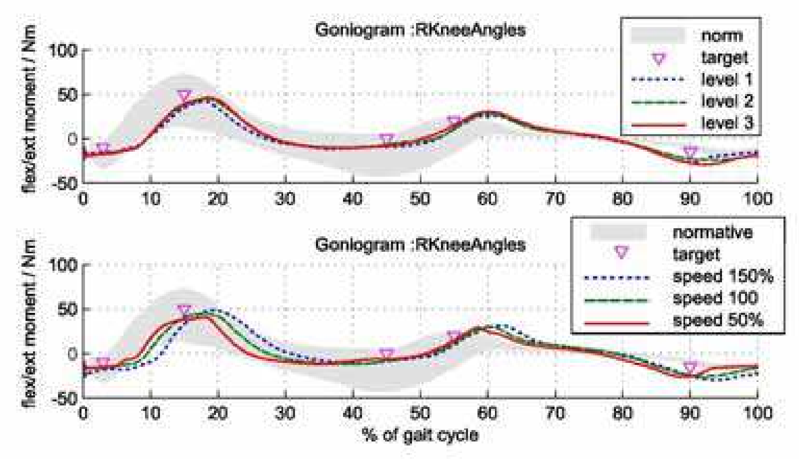

Fig. 8. The knee torque generated by the neurologically intact subjects with contrasted reference values (shaded area) taken from the gait knee joint moment (Winter, 2005). There were no significant changes in the torque when the task difficulty level was changed, but the torque applied was noticeably delayed with increased velocity (target 2) in neurologically intact volunteers.

The overall hit score (Table 1) over all targets demonstrates that the increasing velocity had minor effect in comparison with the difficulty level, what may be the consequence of the fact that the subjects have mastered the VR task. For the easiest difficulty task level (1) a change in hit score with increasing velocity was minor, slightly larger change could be noticed for the task level 2 and poor hit score with high standard deviation was recorded in level 3 (the most difficult), where the success rate was less than 65%.

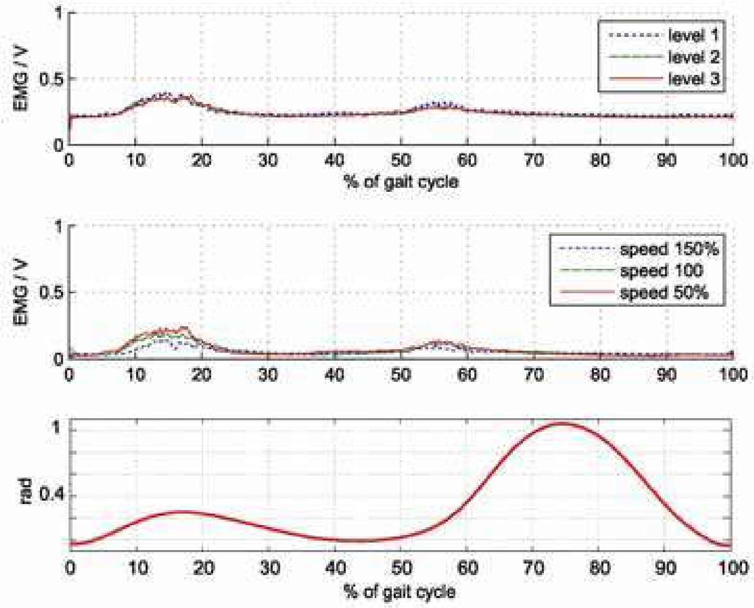

Fig. 9. There were almost no changes in EMG responses in neurologically intact volunteers with increasing difficulty level, but only expected latency which was related to the delayed torque generation. Bellow: The actual position of the dynamometer corresponded to gait knee joint goniogram.

The results of the max torque task (Table 1, Fig. 1) in the CP child show a day-to-day increase in average maximal knee extension joint torque generation in isometric conditions: day 1 – 12.3 Nm (SD 1.1), day 2 – 14.1 Nm (SD 2.3) and day 3 – 17.7 Nm (SD 1.2). The average for knee flexion joint torque: day 1 – 15.3 Nm (SD 2.1), day 2 – 24.1 Nm (SD 3.1) and day 3 – 23.5 Nm (SD 2.1). The normalized time course of the generated joint torque in the CP child showed high oscillations on the first day of the training session VR target tracking task (Fig. 2). The subject was also trying to correct his action by rapid flexion-extension movement, especially when trying to hit the 2nd target. The action resulted in oscillations at the moment where action was required, i.e. between 10 and 30% of the GC. The GC was 15s and treated as very slow action. On the second day of training (Fig. 10 middle panel) the subject showed more precise control of generated joint torque and improved tracking resulted in hitting the target nr. 2. The task execution speed (GC = 10s) was also increased. More precise joint torque control has been demonstrated through the complete task. The lower panel of Fig. 10 shows that the oscillations caused by the quick knee extension/flexion torque have disappeared and the subject managed to control the joint torque as requested by the task. The bold line in Fig. 10 shows the mean value joint torque assessed each day for specific task execution speed and task difficulty level 1.

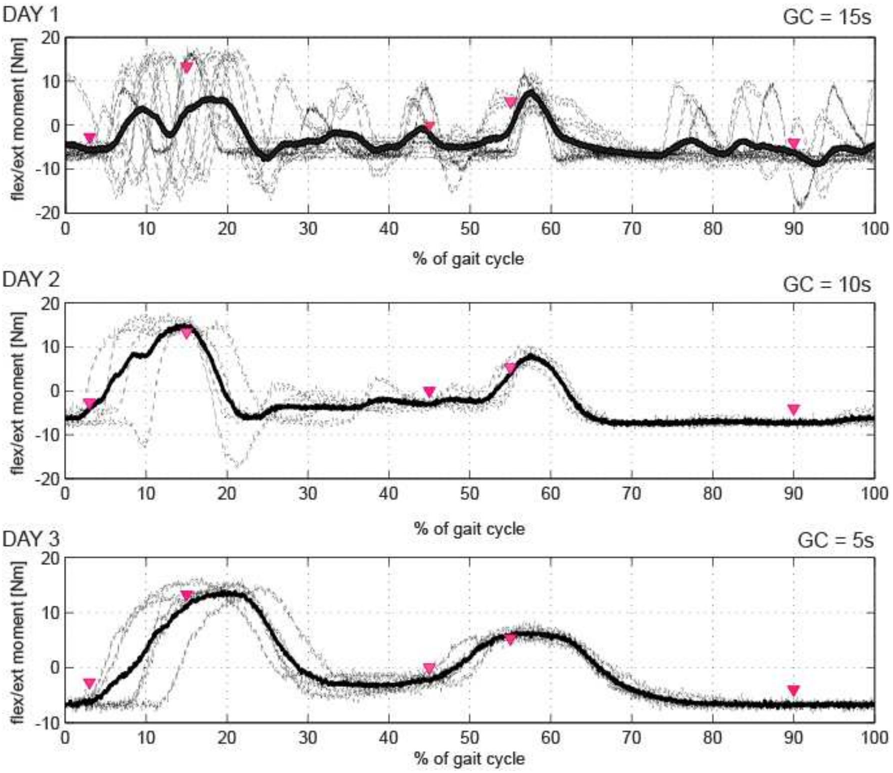

Fig. 10. The assessed knee joint torque in CP child shows oscillations in the range (e.g. target nr 2) where high torque was required on the first day of training. The knee joint torque control has evidently improved as the subject was capable of target tracking almost without any oscillations at the end of the third day of training. Targets are marked with a triangle.

The overall hit statistics (all levels, all targets) also demonstrated an increase in mean hit score (Fig. 11) in the CP child. Results in the lower right Fig. 11 demonstrate the gradual increase of each target hits over all task difficulty levels; target 1 (76 ->86%), target 2 (41 ->50%), target 3 (79 -> 88%), target 4 (67 -> 88%) and target 5 (85 -> 98%). The only decrease (90.5 -> 88.0%) took place at the target 3 from day 2 to day 3, but was considered insignificant ($p > 0.05$). The target 2, which required the highest peak torque generation, also demonstrated statistically significant (41.2 -> 50.0%, $p < 0.05$) target hits increase between the first and the last session.

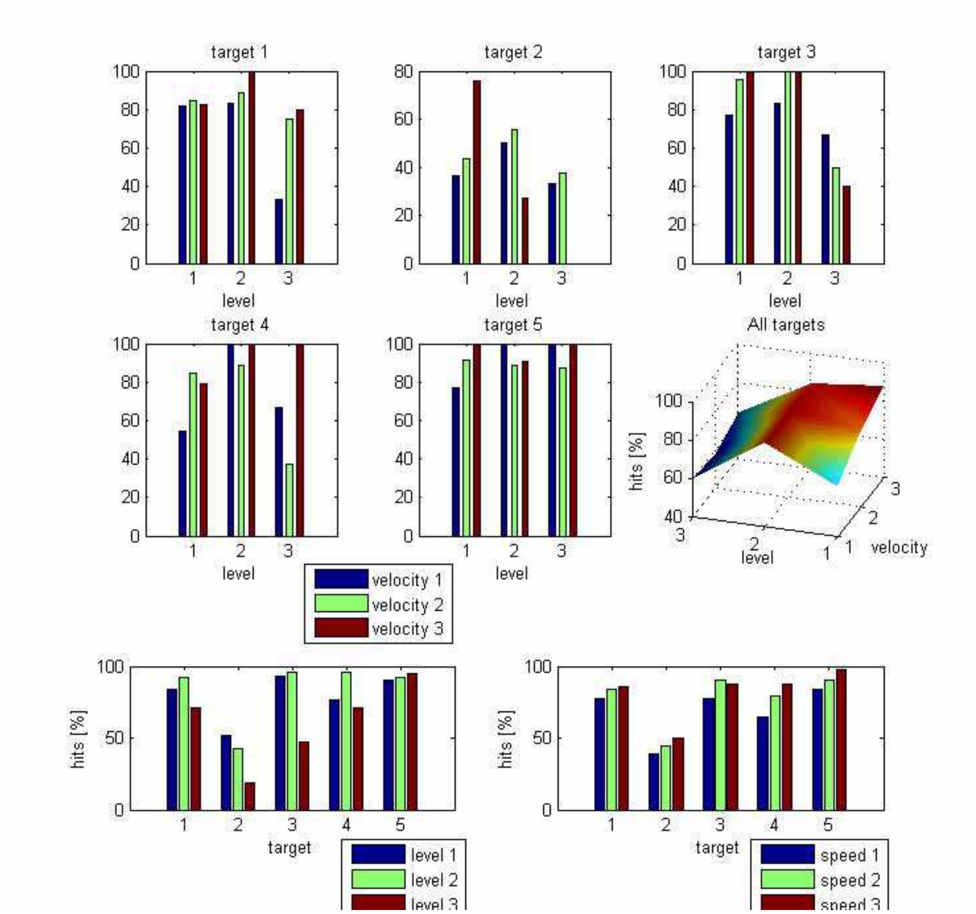

Fig. 11. The mean target hit rate in CP child for each target in VR target tracking (Fig. 2) for each day/speed with standard deviation. The bar graphs show increase in overall target hit rate in three consecutive training days. The VR target hits rate has increased for all targets (except for target nr 3 from day/speed 2 to day/speed 3) in three consecutive training days regardless of the task difficulty level (lower right graph).

6.2 VR dynamic balance training

Fig. 13. shows the mean track times, achieved at the beginning of the therapy and a week later (start end) for each difficulty level. In the first week the subject made an enormous progress, reducing the mean track time from 48s to 42s ($p < 0.05$). On the second week the task was a step more difficult with obstacles on the way, but the score was still encouraging, from 56s to 52s ($p = 0.031$). The level 3 with even more obstacles, which also lengthened the path, also demonstrated progress from 53s to 51s ($p = 0.0157$).

The score of each training track was displayed in seconds together with the object hits (penalty time 5s) and total score:

51s 3 hits (+15s) 66s

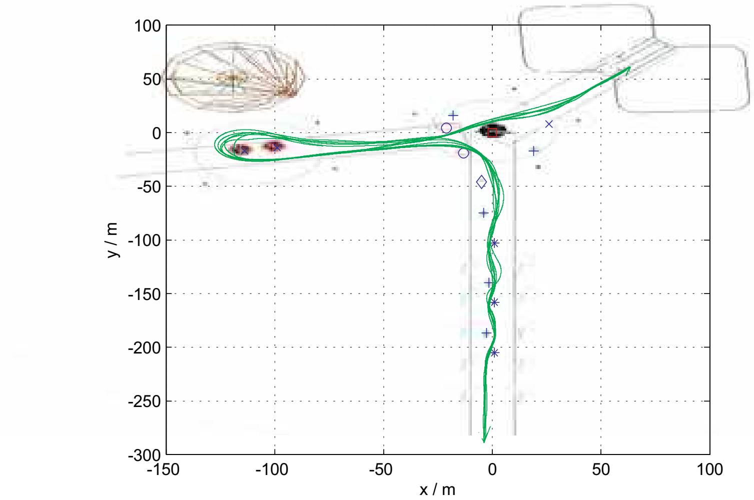

Fig. 12. The top view of the VE task objects (* cans, + benches, O pools, x hydrant,…) with training tracks appended. The VR task started at the lower end of the figure and finished at the upper right corner with entering the building. It is obvious that the subject has hit the tables at the buffet twice, crossed the pool and hit the 2nd and 3rd can.

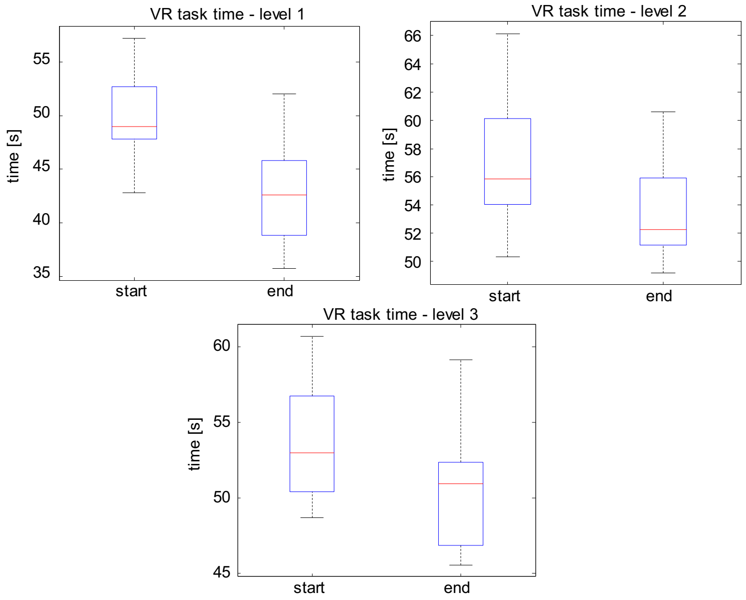

Fig. 13. The upper left graph: Time to complete the task was shortened for 15% in the first week of therapy ($p < 0.05$). The upper right graph: Time to complete the task (level 2) at the end of the second week of therapy was shortened for 8% comparing with results from the beginning of the second week ($p = 0.031$). Bellow: At the end of the third week the average time to complete the task (task level 3) was shortened for 4% ($p = 0.0157$).

For the clinical purposes the therapy has been also evaluated with clinical instruments; BBS, Standing on a single extremity and Timed Up & Go test and 10m walk. The BBS has increased from 50 up to 54 after the treatment. The results of the "Standing on healthy extremity test" improved from 41.10s to 46.82s and on the "affected extremity" improved from 4.87s to 13.63s. Similar improvements were found in "Timed Up & Go test", (from 14.93s to 11.47s) and in "10m walk", where the subject managed to beat the distance in 11.20s, a way faster than before the treatment (12.57s).

7. Discussion

The presented examples demonstrate the use of virtual reality technology in rehabilitation to motivate the subject during the target oriented task and therefore contribute to the augmented rehabilitation efficacy. Both examples enable task difficulty control and task velocity adjustment. The first example introduces a novel approach in selective motor control training. The VR tasks in this example enable and motivate the subjects to fully cooperate with the task which may enhance the rehabilitation outcomes and on the other hand allow creating unique training environments where task constraints can be modified and supervised. Besides, the single muscle group tasks enable identification of some pathological gait causes, which could not be identified only with computer gait analysis (e.g. weak muscle, selective motor control...). The results demonstrated that the day-to-day training in VR environment with integrated real-time feedback may improve the subjects' perceptive and predictive capabilities which may have impact on selective motor control; neurologically intact individuals managed to follow the task difficulty change as they learned the task very quickly. In this case the increased task velocity led to the generated joint torque and adequate muscles' EMG delay. The goal of the particular VR task was to generate joint torque similar to the reference assessed in normal gait (Winter, 2005). The mean generated joint torque was within the standard deviation of the gait normative. Only the curve shape has changed in relation to the task execution velocity. The peak torque at the VR target nr 2 (Fig. 2) was delayed due to the required rapid and strong action to achieve the required torque in order to hit the target. Here the CP child, who had major problems with selective motor control, especially in hip and knee joints, managed to generate the adequate knee joint torque only after a three days of intensive training. We assume that such training may also have impact on gait pattern change in terms of improved selective muscle control during stance.

The second example shows a right-side affected subject who had major problems with balancing and weight transfer, especially when loading his affected extremity, experiencing a VRBT. The subject sometimes left the desired trajectory in VE and hit some obstacles. But as the subject was highly motivated, he was improving his performance on a daily basis. The subject managed to accomplish the task faster, more accurate, even when the physiotherapist increased the difficulty level. The outcomes demonstrated that the subject achieved practically the same track time at the end of therapy with level 3 as at the beginning with level 1, where no obstacles were present. This may lead to the conclusion that the subject has completely mastered the VR task. Besides the objective engineering indicators also the clinical instruments revealed improvement of the subject's clinical status; improved weight balance – standing on the affected extremity, faster in timed up&go and 10m walk test and increased BBS. Especially the 10m walk might be very relevant when considering that it is argued that timing of gait over 10 meters is a valid reliable measure that is currently underused (Wade et al, 1987).

Both presented examples are pilot studies or proof of concept within limitations, but may demonstrate a successful application in clinical/home environment. Besides fun and motivation, which were the key of successful selective motor control training in CP child, it has been demonstrated that hospitalized stroke subject may continue the rehabilitation process at home. Such service may cut the cost on the long term and patients from rural communities and even urban settings with poor access to transportation and therefore limited access to outpatient service could also benefit from telerehabilitation service (Rosen, 1999).

8. Conclusion

After all, "Why actually use the virtual reality in rehabilitation?" might be a legitimate question and is entitled to explanation. Creating appropriate virtual environments for rehabilitation is rather a difficult task, requiring proficiency in subjects' cognitive capabilities, motor control, etc… and is presumably related to high costs. Therefore it would be more convenient to use real environments. But as shown in the chapter the VEs enable creating various tasks, changing parameters, adding, subtracting objects and other modifications that may influence on enhanced learning. Important for motor learning practice is that the VE enables the use of augmented feedback (Holden & Dyar, 2002) about the performance. Another important fact is that the VE can be very simple in the early stage of rehabilitation, constraining the subject to focus only on the key elements of the task – targeted tasks. The VE could be customized for different therapeutic approaches and provide options to guide the subject through the VE and help him to correct errors. One might consider that errors in real environment may result in physical injury or damage of auxiliary objects. Therefore one must consider some of the important advantages that VE offer over real environments; safety, smaller space and less equipment requirements, repeatability (Mirelman et al, 2009) faster change of task requirements or task adaptation and finally lower cost, especially when the patients can practice on their own without presence of the medical professional or even at home – telerehabilitation.

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Recent Advances in Biomedical Engineering

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The field of biomedical engineering has expanded markedly in the past ten years. This growth is supported by advances in biological science, which have created new opportunities for development of tools for diagnosis and therapy for human disease. The discipline focuses both on development of new biomaterials, analytical methodologies and on the application of concepts drawn from engineering, computing, mathematics, chemical and physical sciences to advance biomedical knowledge while improving the effectiveness and delivery of clinical medicine. Biomedical engineering now encompasses a range of fields of specialization including bioinstrumentation, bioimaging, biomechanics, biomaterials, and biomolecular engineering. Biomedical engineering covers recent advances in the growing field of biomedical technology, instrumentation, and administration. Contributions focus on theoretical and practical problems associated with the development of medical technology; the introduction of new engineering methods into public health; hospitals and patient care; the improvement of diagnosis and therapy; and biomedical information storage and retrieval. The book is directed at engineering students in their final year of undergraduate studies or in their graduate studies. Most undergraduate students majoring in biomedical engineering are faced with a decision, early in their program of study, regarding the field in which they would like to specialize. Each chosen specialty has a specific set of course requirements and is supplemented by wise selection of elective and supporting coursework. Also, many young students of biomedical engineering use independent research projects as a source of inspiration and preparation but have difficulty identifying research areas that are right for them. Therefore, a second goal of this book is to link knowledge of basic science and engineering to fields of specialization and current research. The editor would like to thank the authors, who have committed so much effort to the publication of this work.

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